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APPENDIX C
CONE PENETRATION TESTS

APPENDIX C
CONE PENETRATION TESTS
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APPENDIX C

CONE PENETRATION TESTS

C.1 GENERAL

The field exploration program for the Greenwood Subsurface Characterization Study included conducting 22 cone penetration tests (CPTs). The CPTs were advanced to depths ranging from 3.3 to 39.7 feet at selected locations throughout the Greenwood study area, where subsurface information was limited. The approximate exploration locations are shown on the Exploration Location Map (Figure 3).

The CPT develops a continuous subsurface profile of soil conditions at a particular location. The testing was performed by Northwest Cone Exploration, Inc. (NCE), under subcontract to Shannon & Wilson, Inc., on December 8, 9, and 11, 2003. The work was completed in general accordance with procedures outlined in the American Society for Testing and Materials (ASTM) Designation: D 3441, Test Method for Deep, Quasi-static, Cone and Friction-Cone Penetration Tests of Soil. Soil samples are not obtained in this test method.

C.2 FIELD EQUIPMENT

The piezocene apparatus used by NCE is a Hogentogler system. In this test, steel rods with a cone tip on the end are pushed hydraulically into the soil at a relatively constant rate of approximately 2 centimeters per second (cm/sec). Readings are recorded every 5 centimeters (cm). The cone tip is connected to a stationary friction sleeve and has a cross-sectional area of 10 cm^2 , a surface area of 15 cm^2 , and an angle of 30 degrees from the axis. The area ratio for the tip is 0.8. The stationary friction sleeve has the same diameter as the cone tip but a surface area of 150 cm^2 . The cone tip and friction sleeve assembly is about 50 cm long and is pushed into the ground by steel rods, about 1 meter long. An electronic cable is prestrung through the rods. This cable provides power to the instruments and communication between the instrument and a computer. The system is powered by a 12-volt deep cycle battery, which is recharged periodically.

The CPT instrument is capable of recording tip resistance, sleeve friction, pore pressure, and inclination as it penetrates into the ground. The cone has a tip capacity of 10 tons or approximately 1,000 tons per square foot (tsf). Tip accuracy is approximately plus or minus 0.1 tsf. The friction sleeve has a capacity of 10 tsf with an accuracy of plus or minus 0.01 tsf.

The cone is a subtraction type cone, which senses the tip resistance on one set of strain gauges and senses tip resistance plus side friction on another set of strain gauges. The frictional reading is determined by electronically subtracting the tip reading from the combined reading. The pore pressure sensor has a capacity of 500 pounds per square foot (psf) with an accuracy of plus or minus 0.1 pounds per square inch (psi). The inclinometer has a full range capability of ten degrees with an accuracy of approximately 0.1 degree.

C.3 TEST PROCEDURES

As the cone penetrates the soil, measurements of tip resistance, sleeve friction, pore pressure, and inclination are electrically transmitted through the electronic cable to the ground surface and then displayed and recorded on a portable computer. The cone was pushed into the ground at a rate of 2 cm/sec and readings were recorded at intervals of every 5 cm. Testing was terminated when either the penetration resistance exceeded the capacity of the hydraulic system, or rebounding (bending) of the cone penetrometer push rods became excessive. The tip, filter element, and friction sleeve assemblies were disassembled and cleaned between holes.

The CPT data consists of cone tip resistance, sleeve friction, friction ratio (ratio of sleeve friction to cone tip resistance), and pore pressure versus depth. This data was processed and interpreted by Shannon & Wilson, Inc. and NCE. Soil parameters were estimated based on published correlations shown in the following table:

SOIL PARAMETERS ESTIMATED FROM CPT TESTS

Soil Parameter	Published Reference and Year
Soil Behavior Type (Classification)	Robertson and Campanella, 1989 Robertson and Campanella, 1983
Angle of Internal Friction	Kulhawy, 1994
Equivalent Standard Penetration Test (SPT) N-value (uncorrected)	Robertson and Campanella, 1989
Undrained Shear Strength	Robertson and Campanella, 1989

C.4 TEST RESULTS

Interpreted soil description, corrected cone tip resistance, friction ratio, and pore pressure, as well as the estimated soil properties of internal friction angle, undrained shear strength, and equivalent uncorrected N-value, are plotted versus depth on the logs presented in this appendix

as Figures C-1 through C-22. In addition, pore pressure dissipation tests were conducted on selected CPTs. Pore pressure dissipation tests are performed by stopping cone penetration and allowing pore pressure to dissipate. The dissipation tests were used to calculate groundwater depths and elevations, and are summarized in Table G-4, Appendix G.

C.5 REFERENCE

American Society for Testing and Materials (ASTM), 2003, Annual book of ASTM standards: Construction, v. 4.08, Soil and Rock (I): D 420 – D 5779: West Conshohocken, Pa.

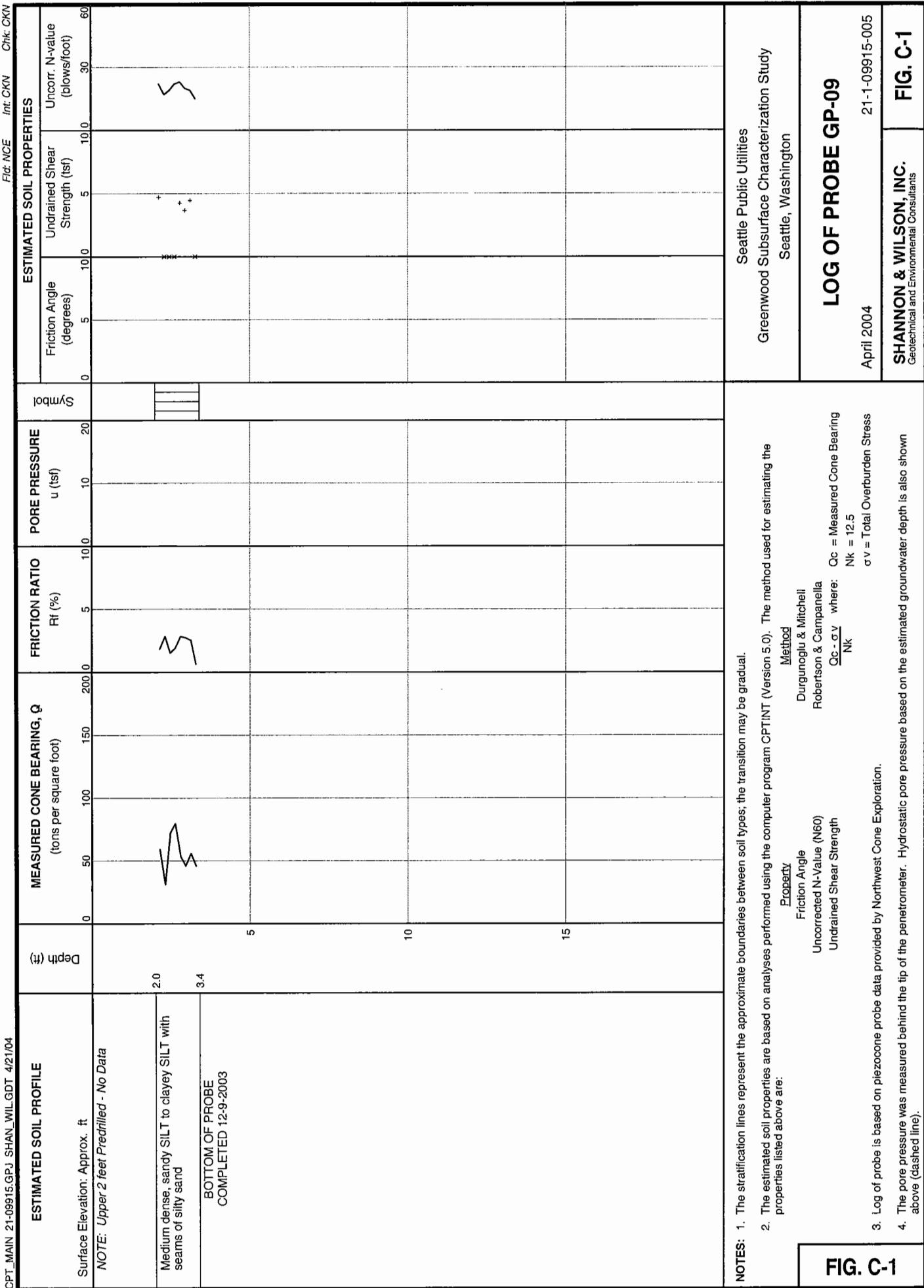


FIG. C-1

Int: CKN Chk: CKN
Fit: NCE

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LOG OF PROBE GP-09

21-1-09915-005

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FIG. C-1

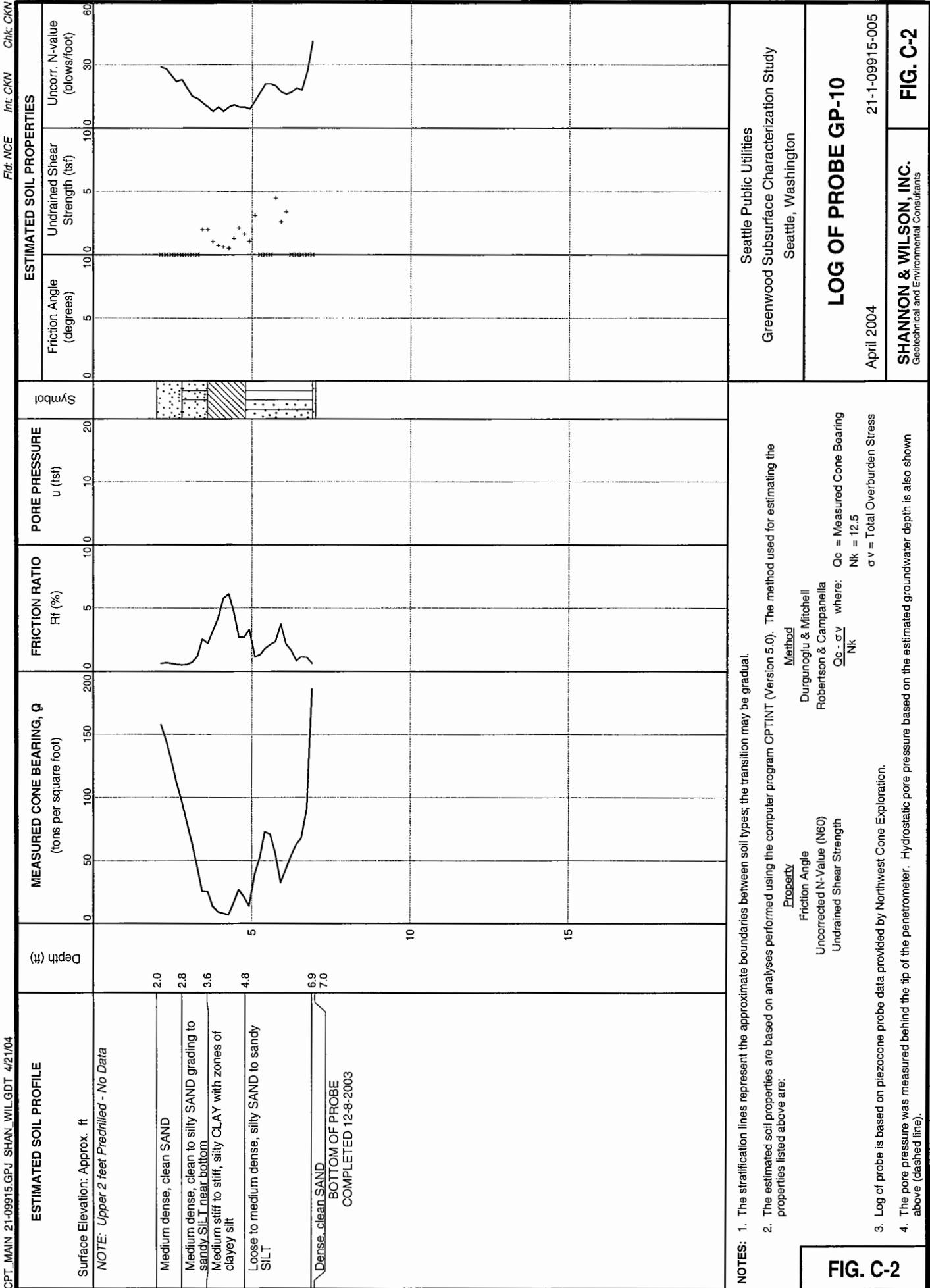
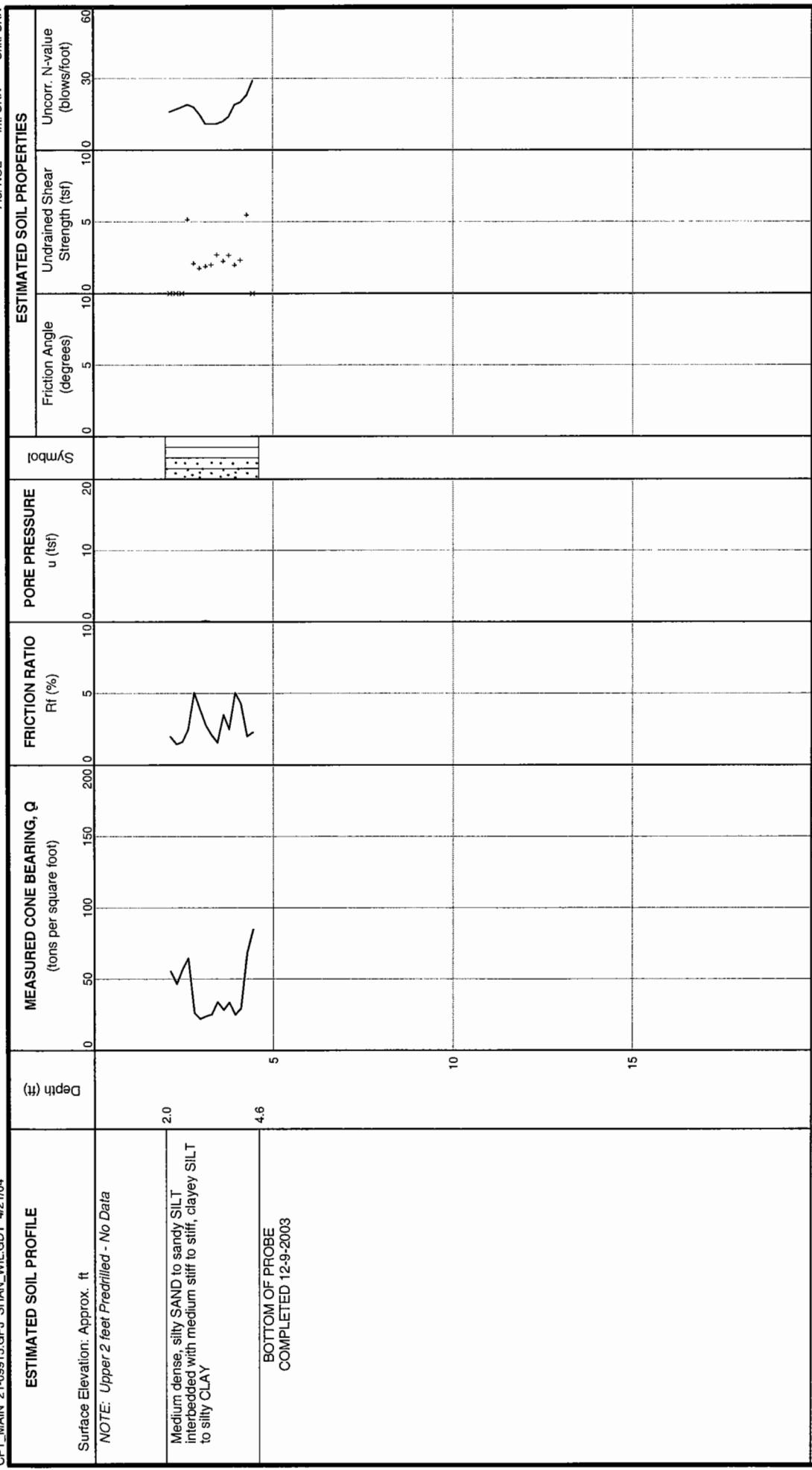


FIG. NCE Int: CKN Crnk: CKN
ESTIMATED SOIL PROPERTIES
 Friction Angle (degrees) Un drained Shear Strength (ft) Uncorr. N-value (blows/foot)

FIG. C-2
LOG OF PROBE GP-10
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FIG. C-2

FIG. C-2
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NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Qc - \sigma v}{Nk}$ where: $Qc = \text{Measured Cone Bearing}$
 $Nk = 12.5$
 $\sigma v = \text{Total Overburden Stress}$

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LOG OF PROBE GP-12

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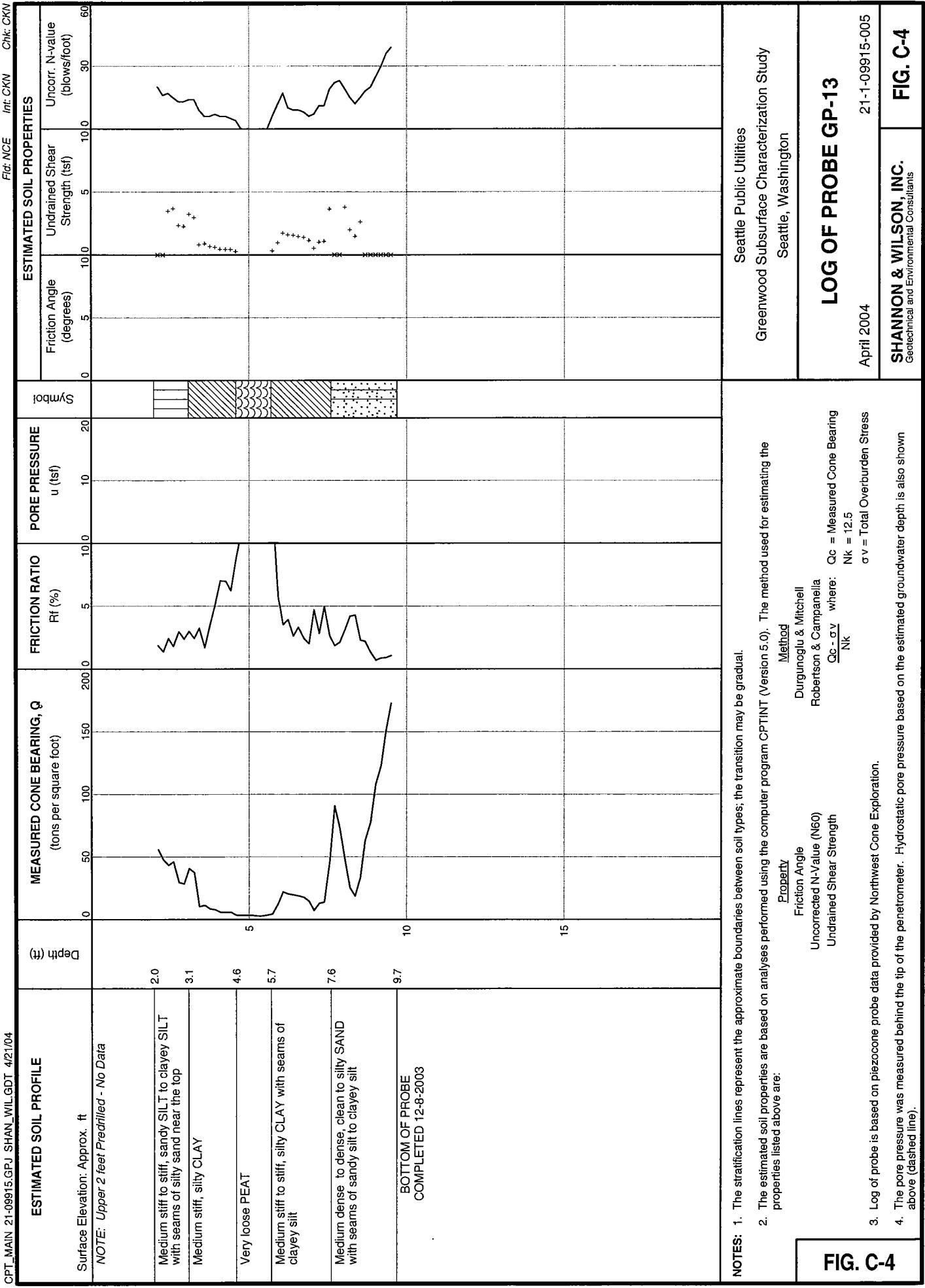
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FIG. C-3

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

FIG. C-3



- NOTES:**
1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.
 2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Q_c - \sigma_v}{N_k}$ where:
 Q_c = Measured Cone Bearing
 N_k = 12.5

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

FIG. C-4

21-1-09915-005

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LOG OF PROBE GP-13

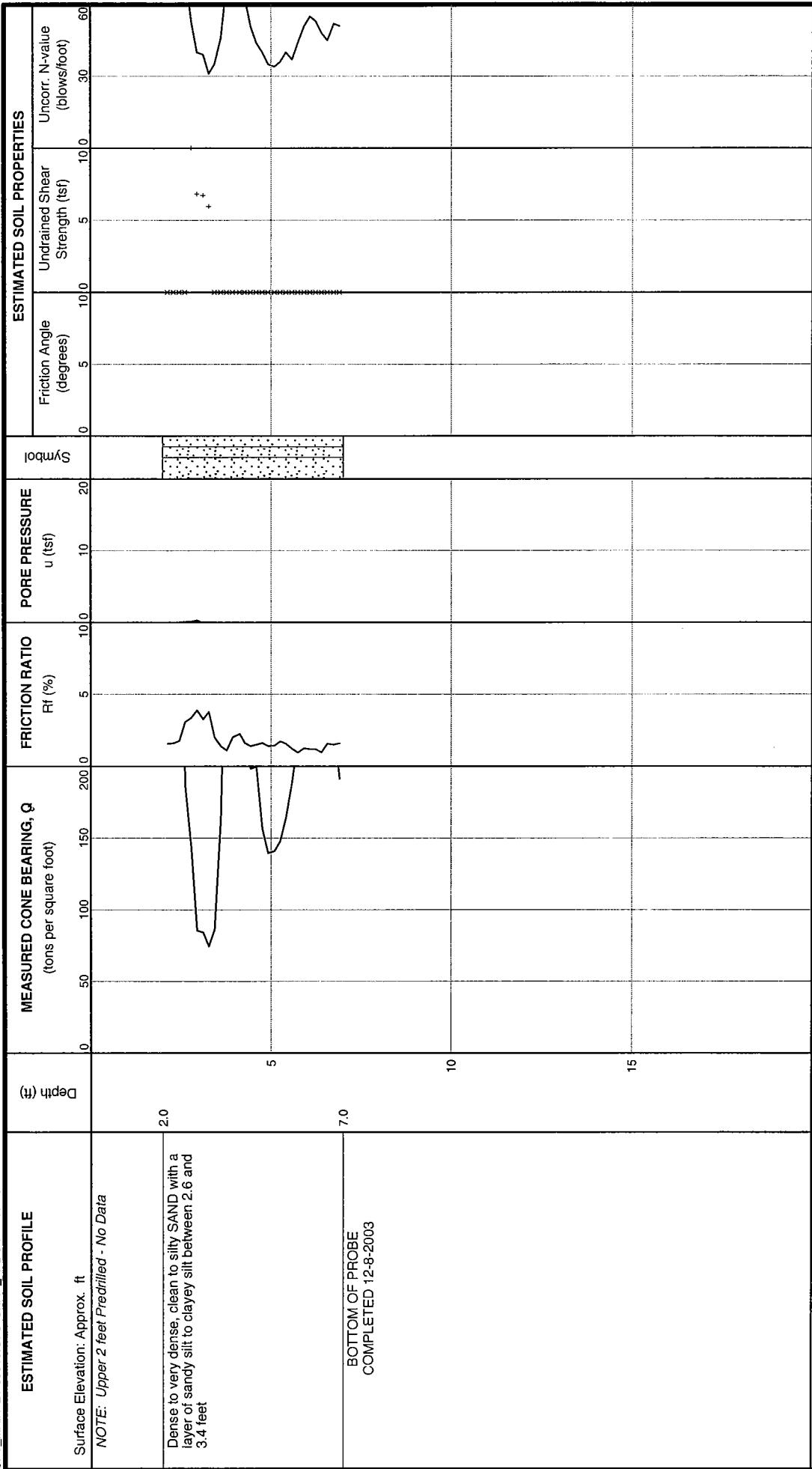
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FIG. C-4

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NOTES:

1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.
2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property	Method
Friction Angle	Durgunoglu & Mitchell
Uncorrected N-Value (N60)	Robertson & Campanella
Undrained Shear Strength	$\frac{Q_c - \sigma_v}{N_k}$ where: Q_c = Measured Cone Bearing N_k = 12.5 σ_v = Total Overburden Stress

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.
4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

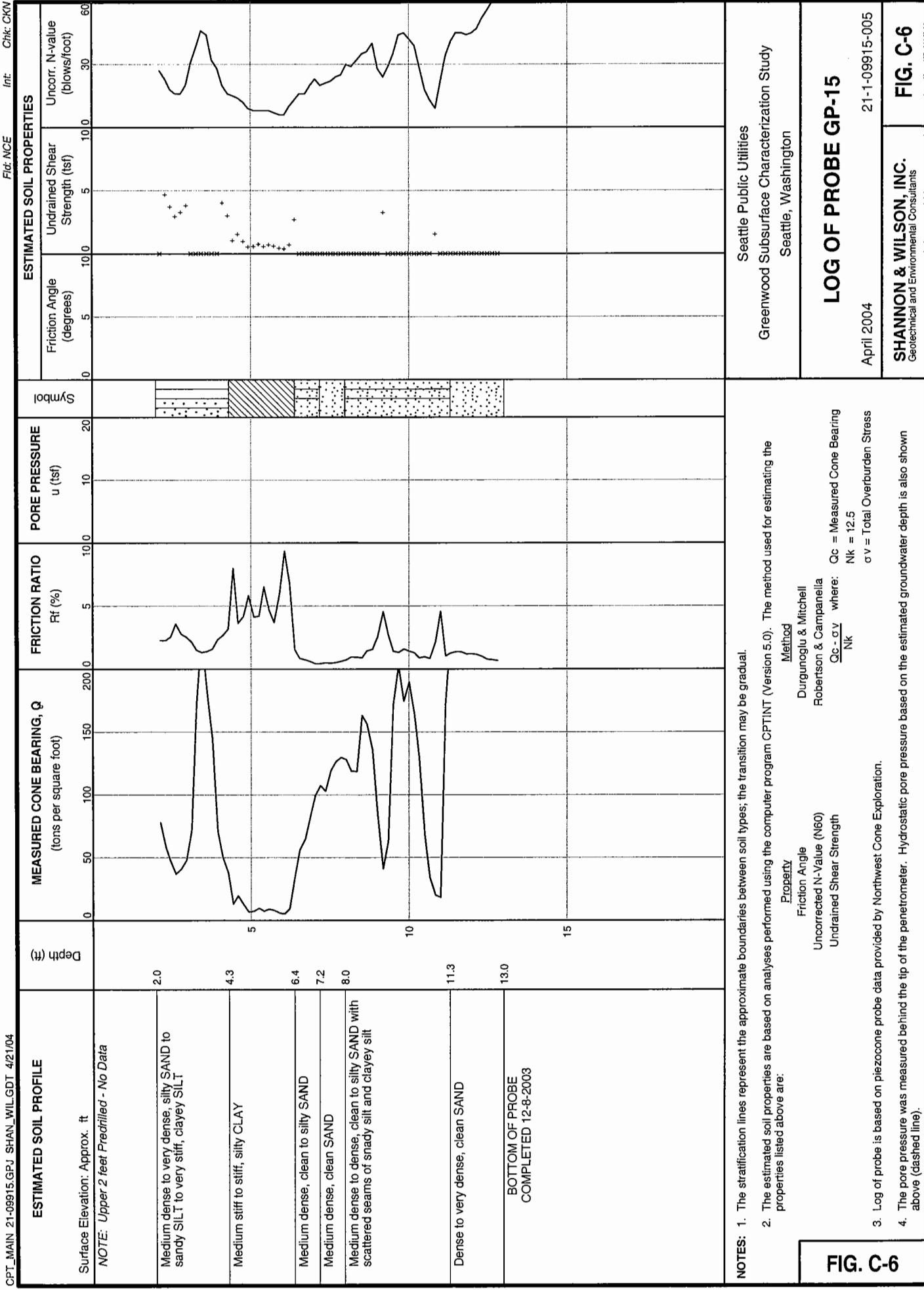
FIG. C-5

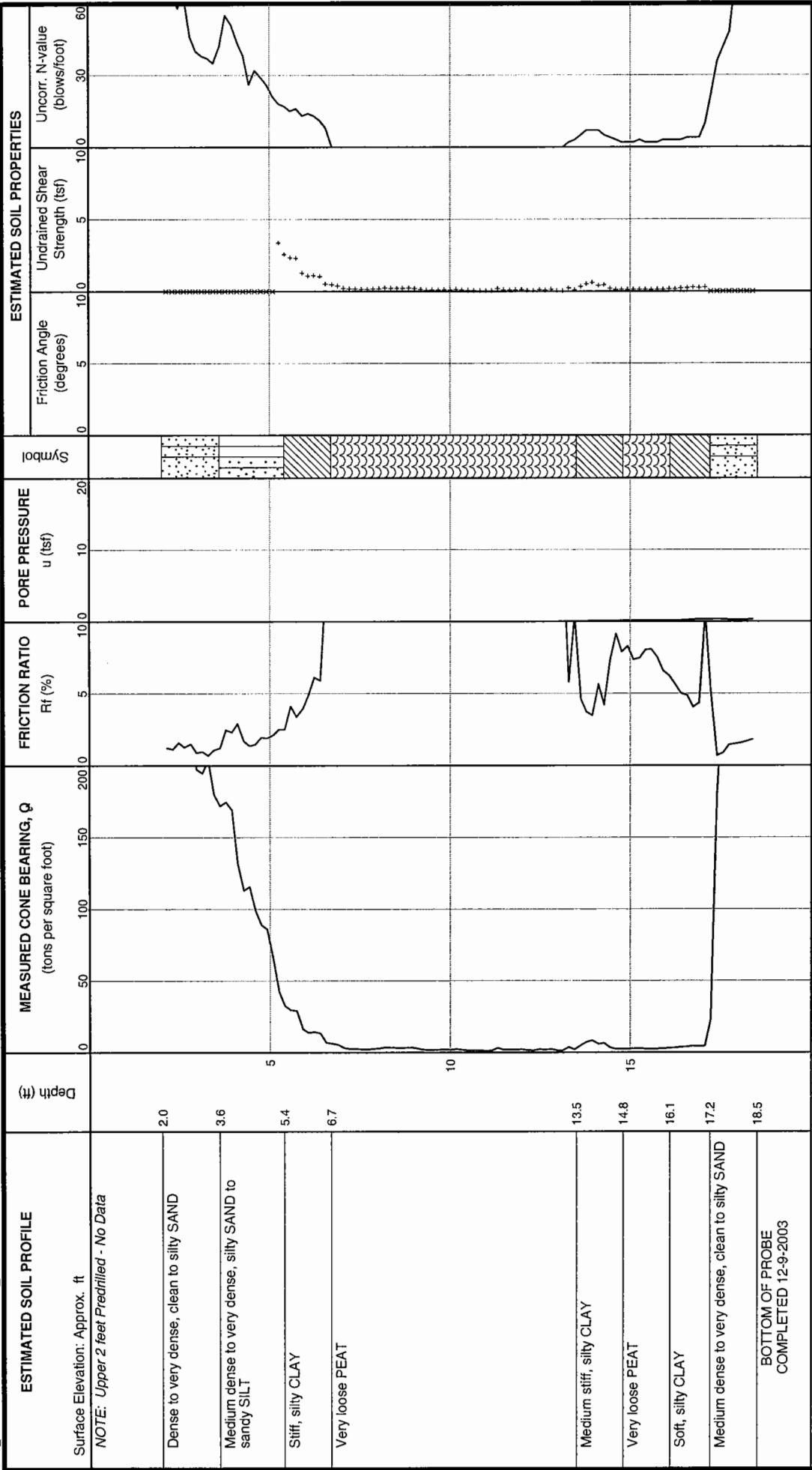
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LOG OF PROBE GP-14

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FIG. C-5





NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-Value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Qc - \sigma v}{Nk}$ where: Qc = Measured Cone Bearing
 Nk = 12.5
 σv = Total Overburden Stress

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

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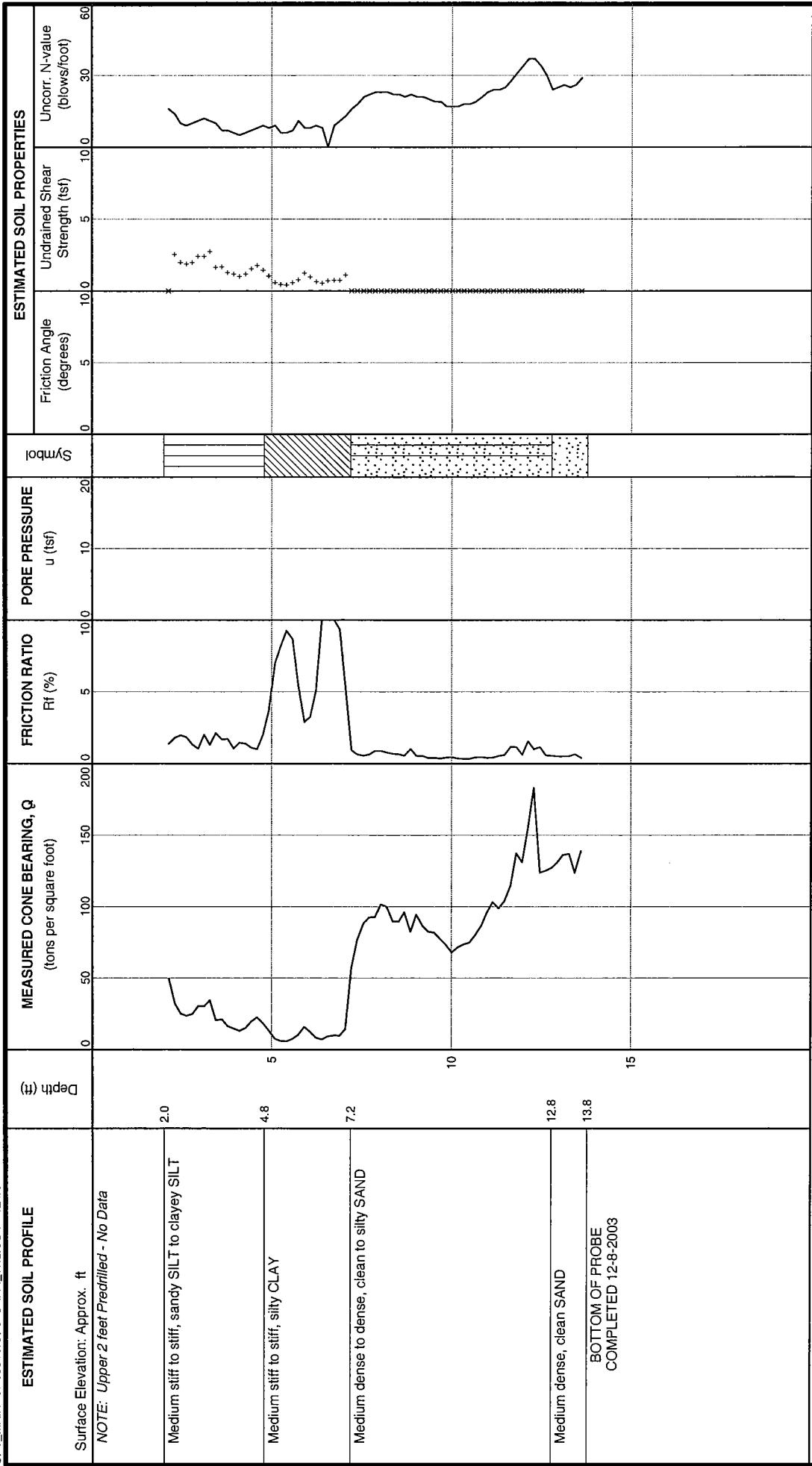
LOG OF PROBE GP-16

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FIG. C-7

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FIG. C-7



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-Value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Q_c - \sigma_v}{N_k}$ where: Q_c = Measured Cone Bearing
 N_k = 12.5
 σ_v = Total Overburden Stress

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LOG OF PROBE GP-17

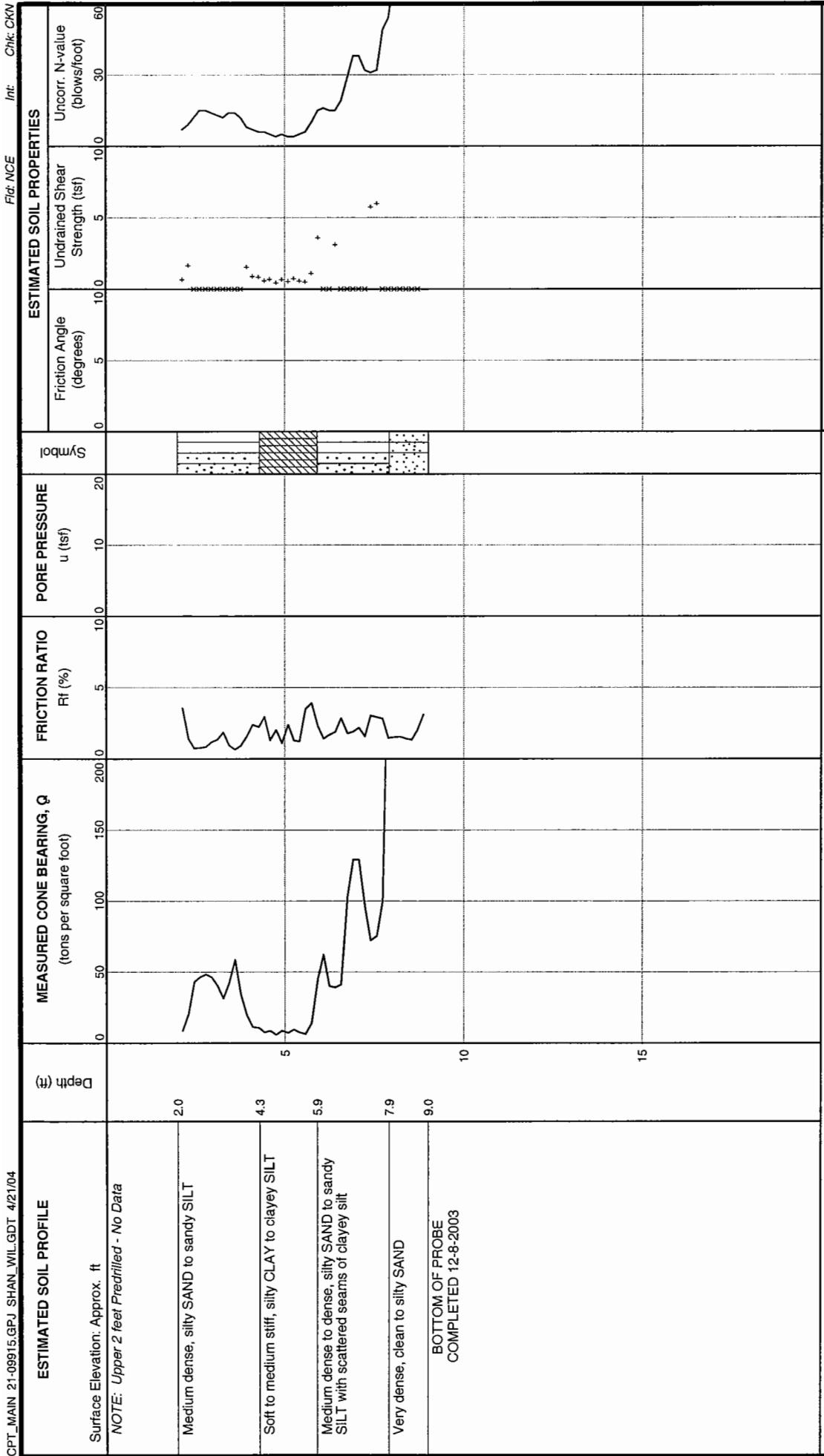
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FIG. C-8

- Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.
- The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).
- Long of probe is based on piezocene probe data provided by Northwest Cone Exploration.

FIG. C-8



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-Value ($\{N_0\}$)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Q_c - \sigma_v}{N_k}$ where: Q_c = Measured Cone Bearing
 N_k = 12.5
 σ_v = Total Overburden Stress

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

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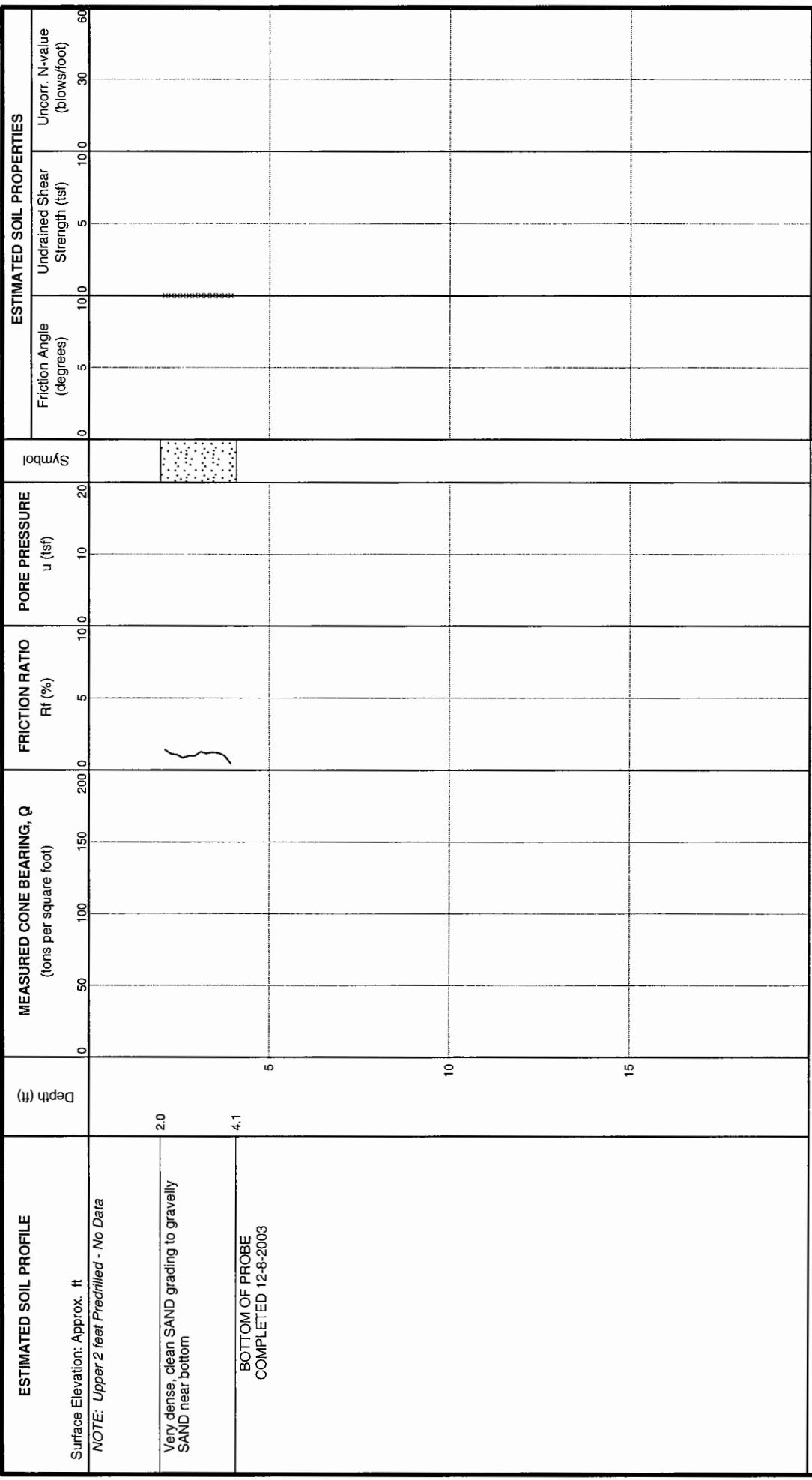
LOG OF PROBE GP-18

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FIG. C-9

FIG. C-9



NOTES:

1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.
2. The estimated soil properties are based on analyses performed using the computer program CPINT (Version 5).

Q_c = Measured Cone Bearing
 N_k = 12.5

$$\sigma_v = \text{Total Overburden Stress}$$

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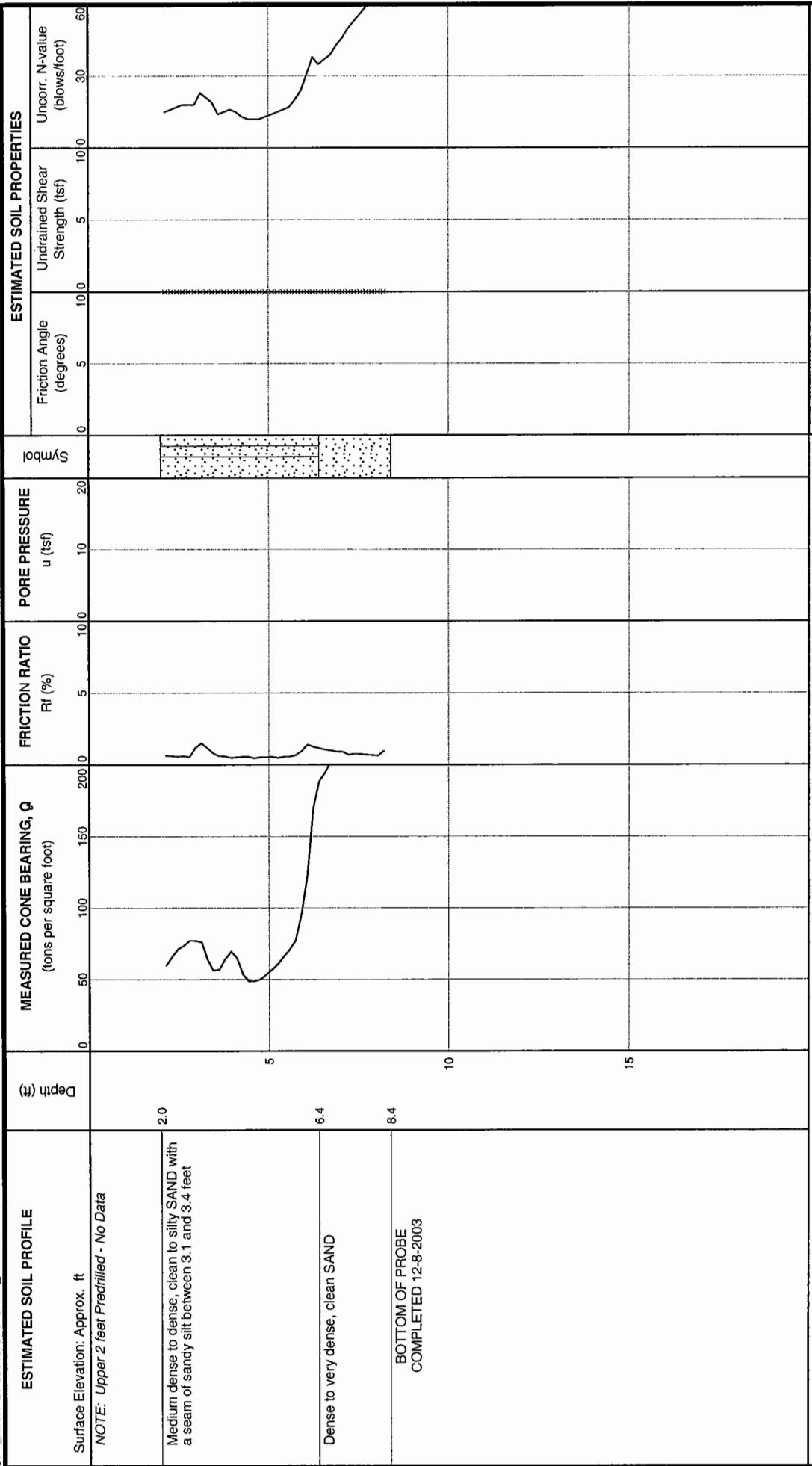
LOG OF PROBE GP-19

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FIG. C-10

FIG. C-10



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property

Friction Angle

Uncorrected N-value (N60)

Undrained Shear Strength

$Q_c - \sigma_v$ where: Q_c = Measured Cone Bearing

$N_k = 12.5$

σ_v = Total Overburden Stress

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LOG OF PROBE GP-20

21-1-03915-005

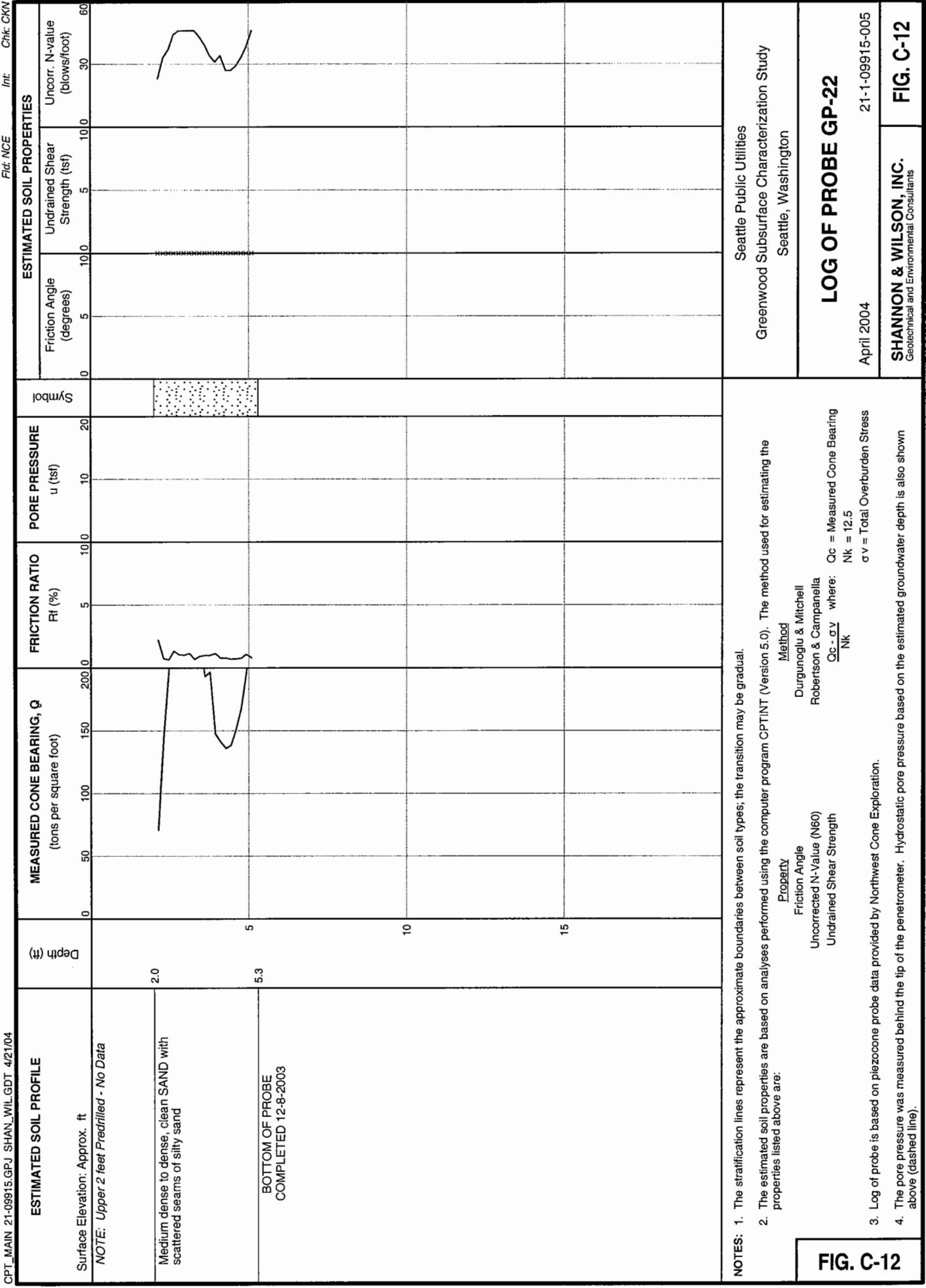
FIG. C-11

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3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

FIG. C-11

**FIG. C-12**

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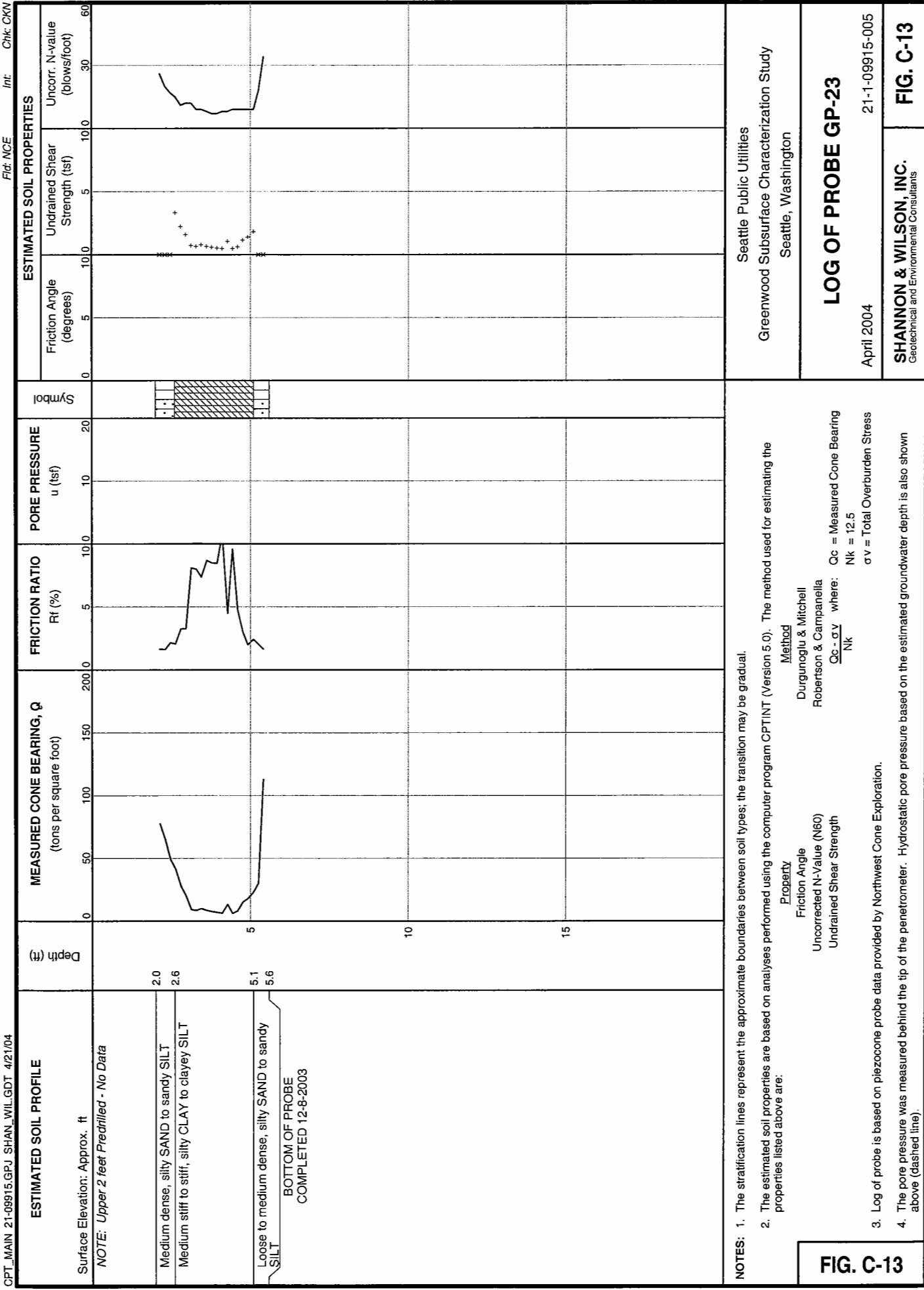
FIG. C-12

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NOTES:

1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.
2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

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Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Q_c - \sigma_v}{N_k}$ where: Q_c = Measured Cone Bearing
 N_k = 12.5

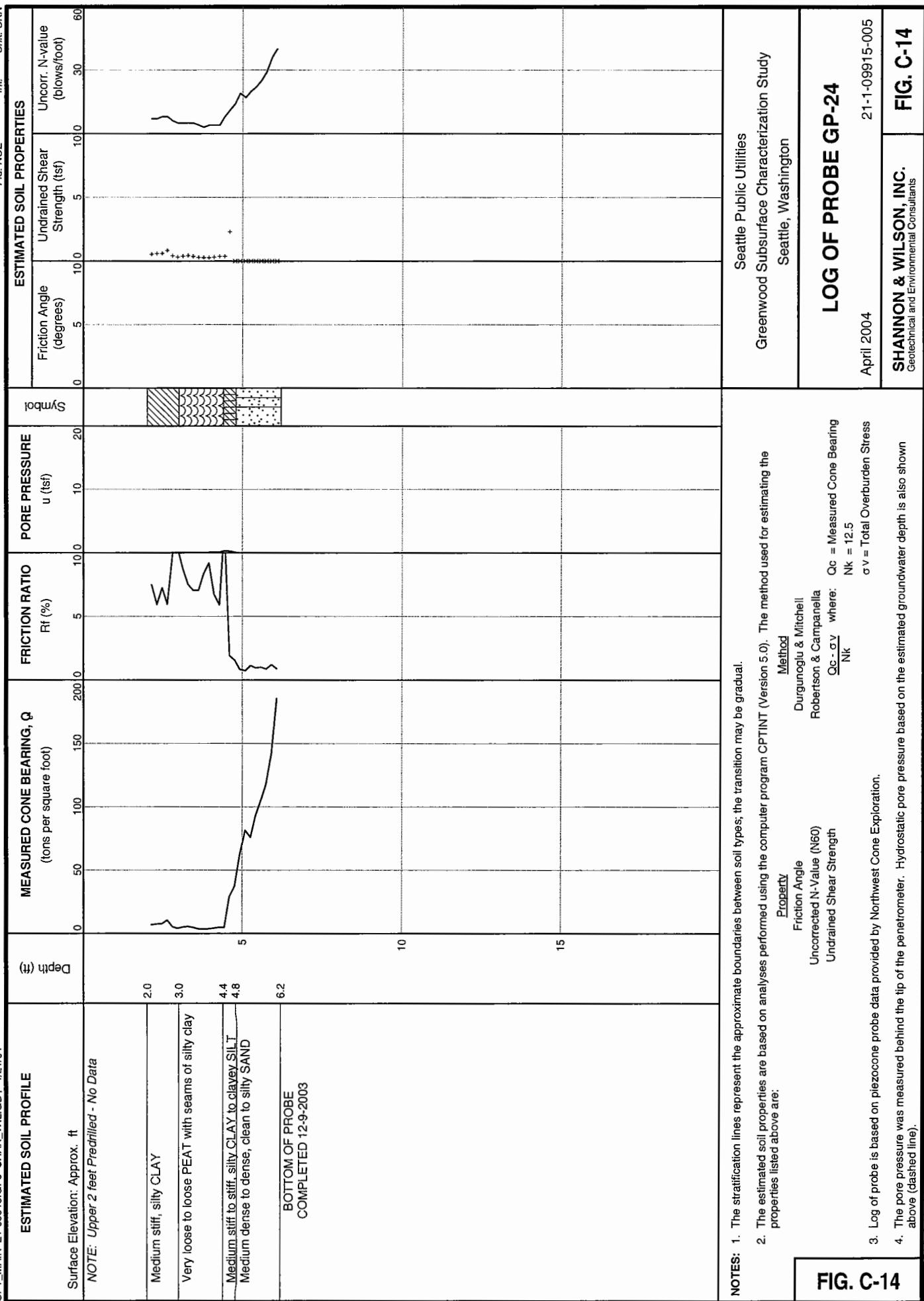
 σ_v = Total Overburden Stress

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FIG. C-13

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.
4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

FIG. C-13

**FIG. C-14**

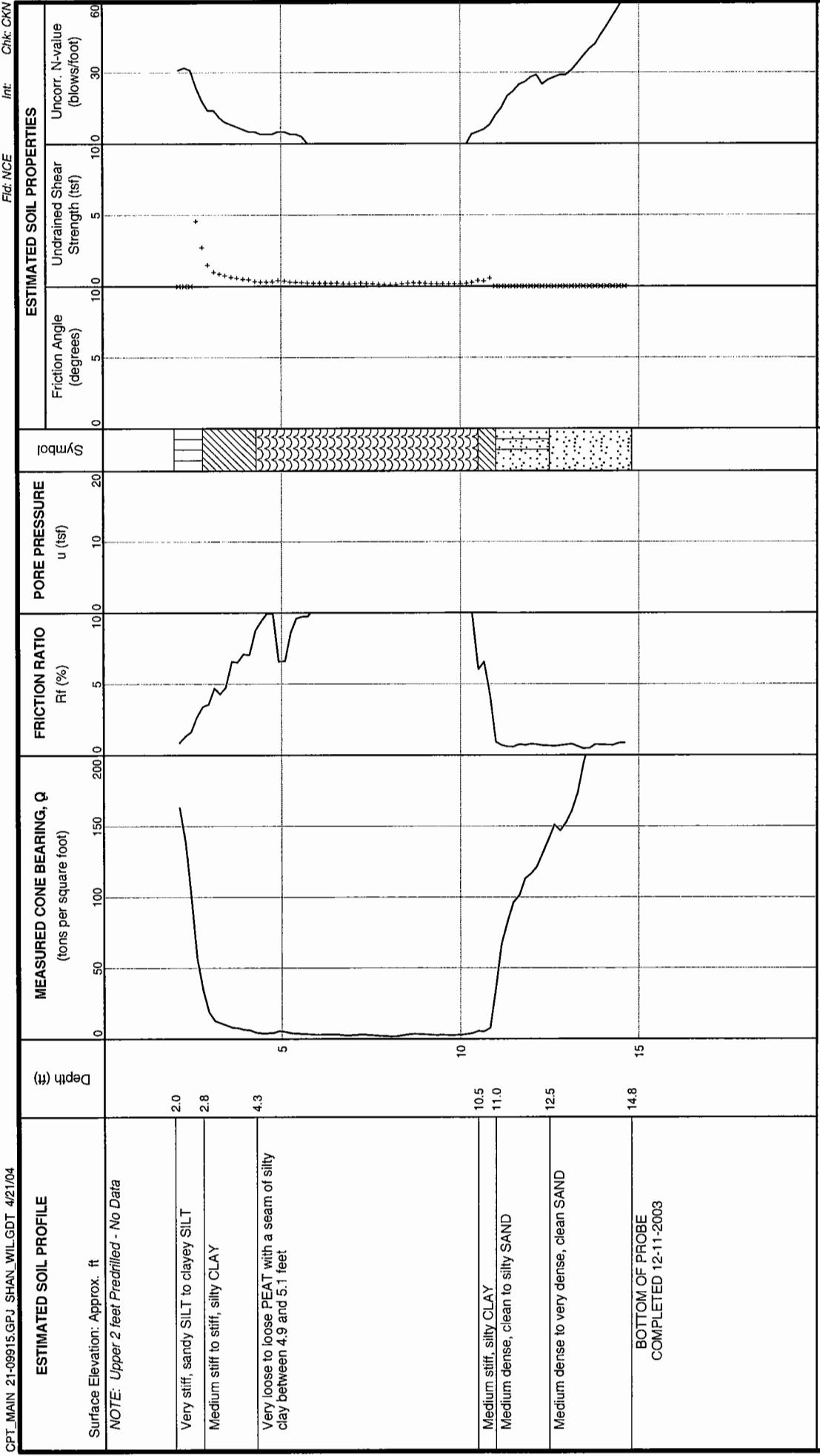
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FIG. C-14



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property

Friction Angle

Uncorrected N-Value (N60)

Undrained Shear Strength

Method

Durgunoglu & Mitchell

Robertson & Campanella

$\frac{Q_c - \sigma_v}{N_k}$ where: Q_c = Measured Cone Bearing

$N_k = 12.5$

σ_v = Total Overburden Stress

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LOG OF PROBE GP-26

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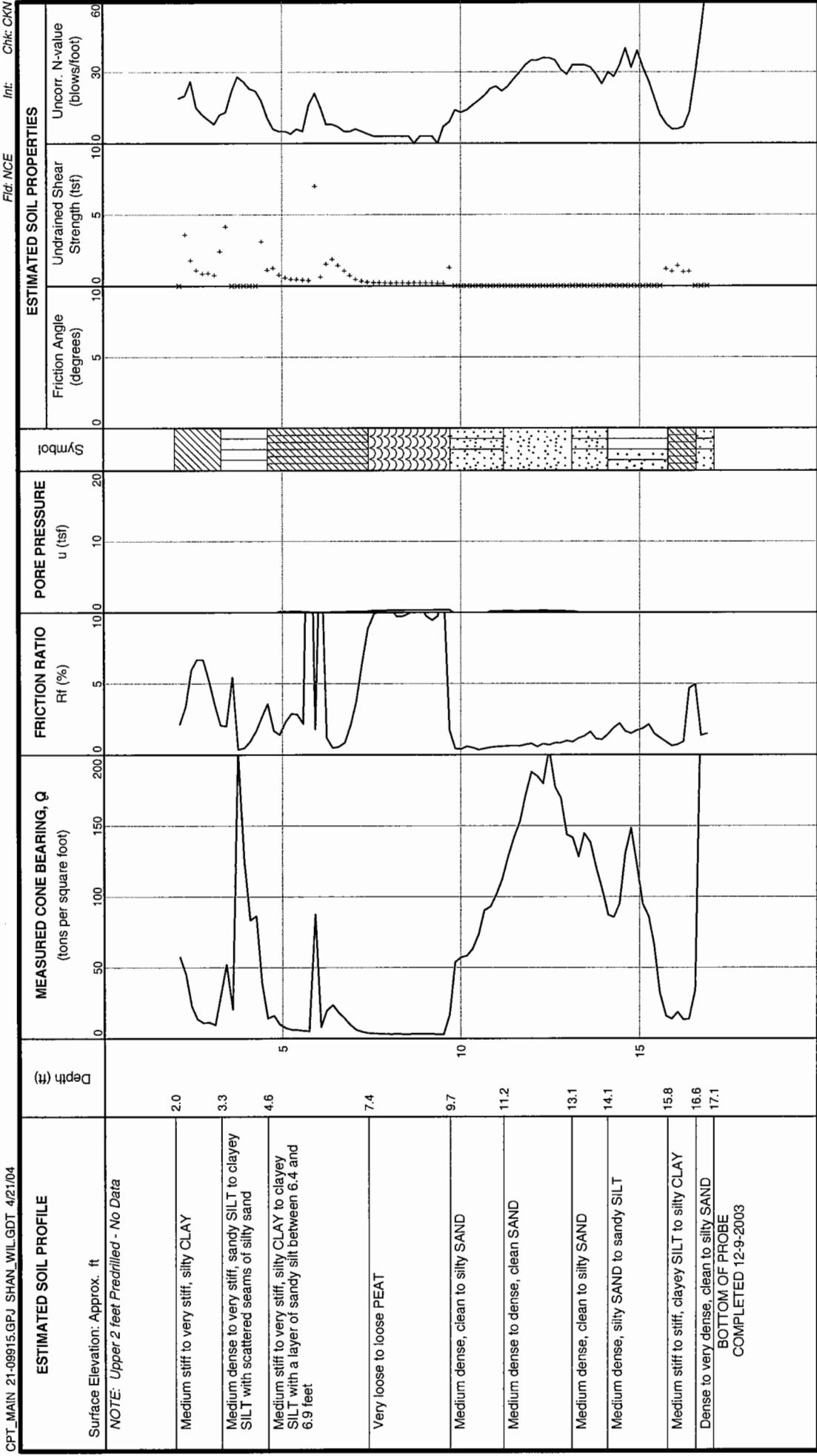
FIG. C-15

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

FIG. C-15

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NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-Value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Qc - \sigma_v}{Nk}$ where:
Qc = Measured Cone Bearing
Nk = 12.5
 σ_v = Total Overburden Stress

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FIG. C-16

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

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LOG OF PROBE GP-27
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FIG. C-16

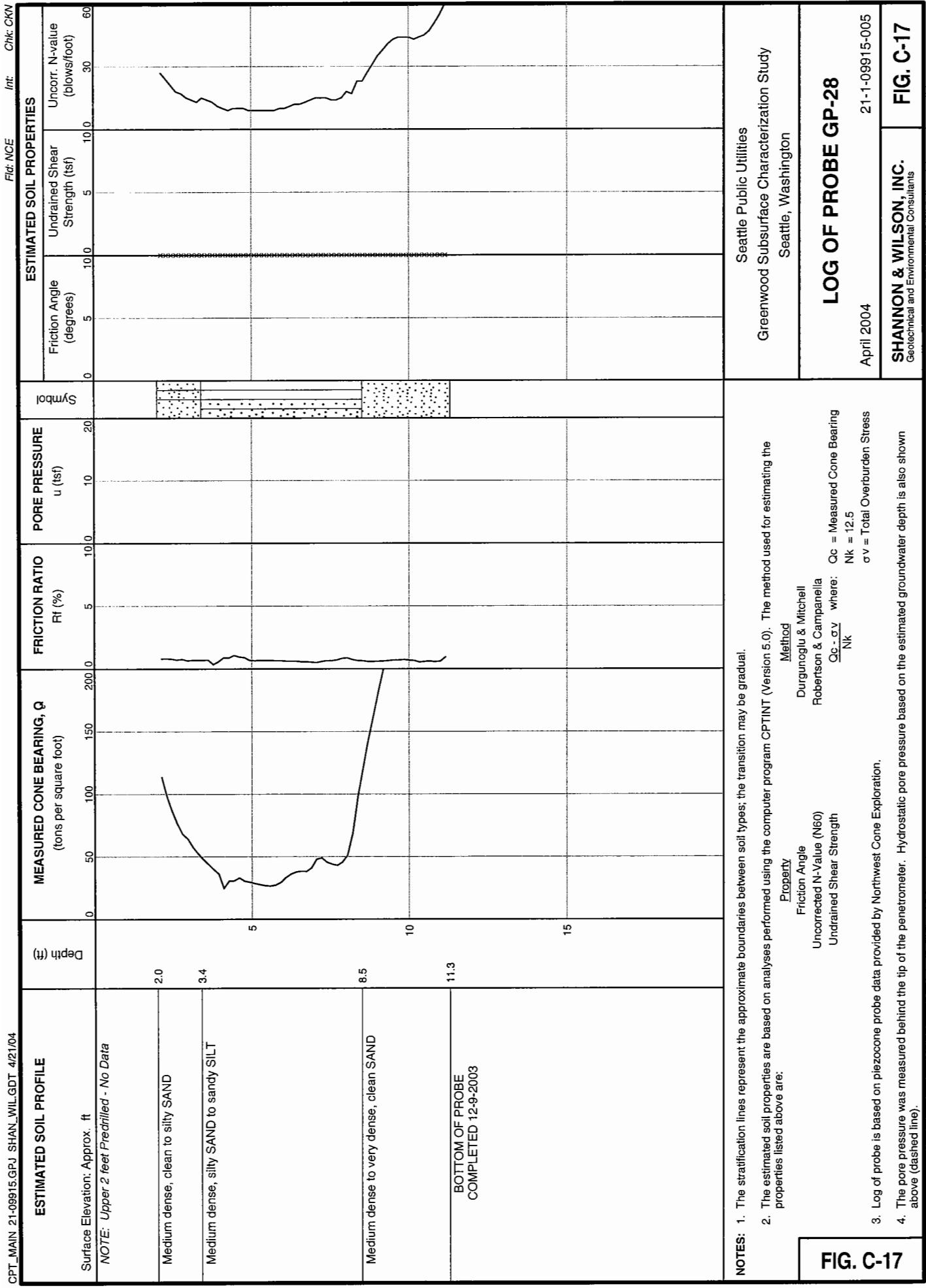
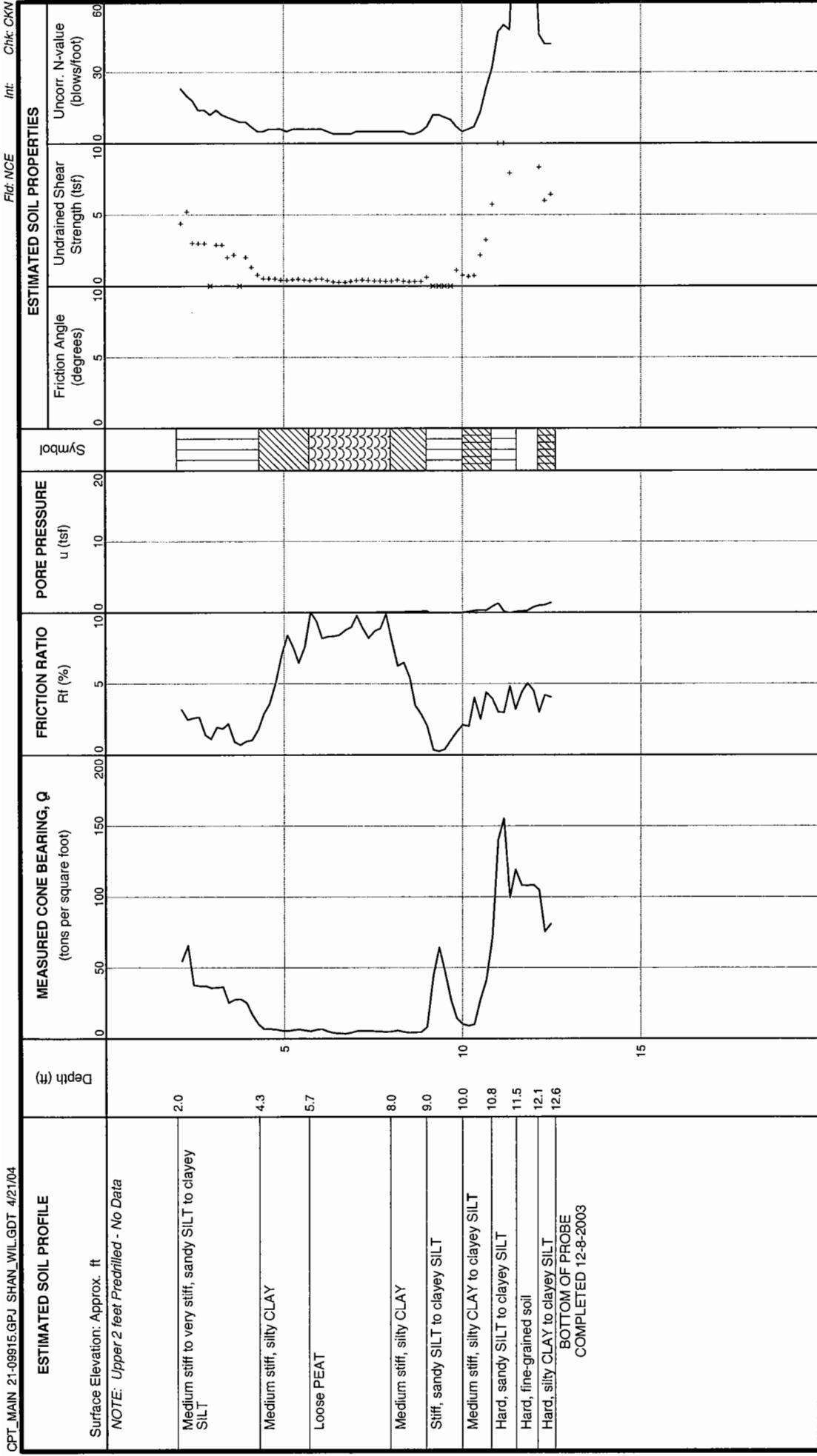


FIG. NCE
Int: Chk: CKN
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FIG. C-17



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-Value (N60)
Un-drained Shear Strength

3. Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

4. The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).

FIG. C-18

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FIG. C-18

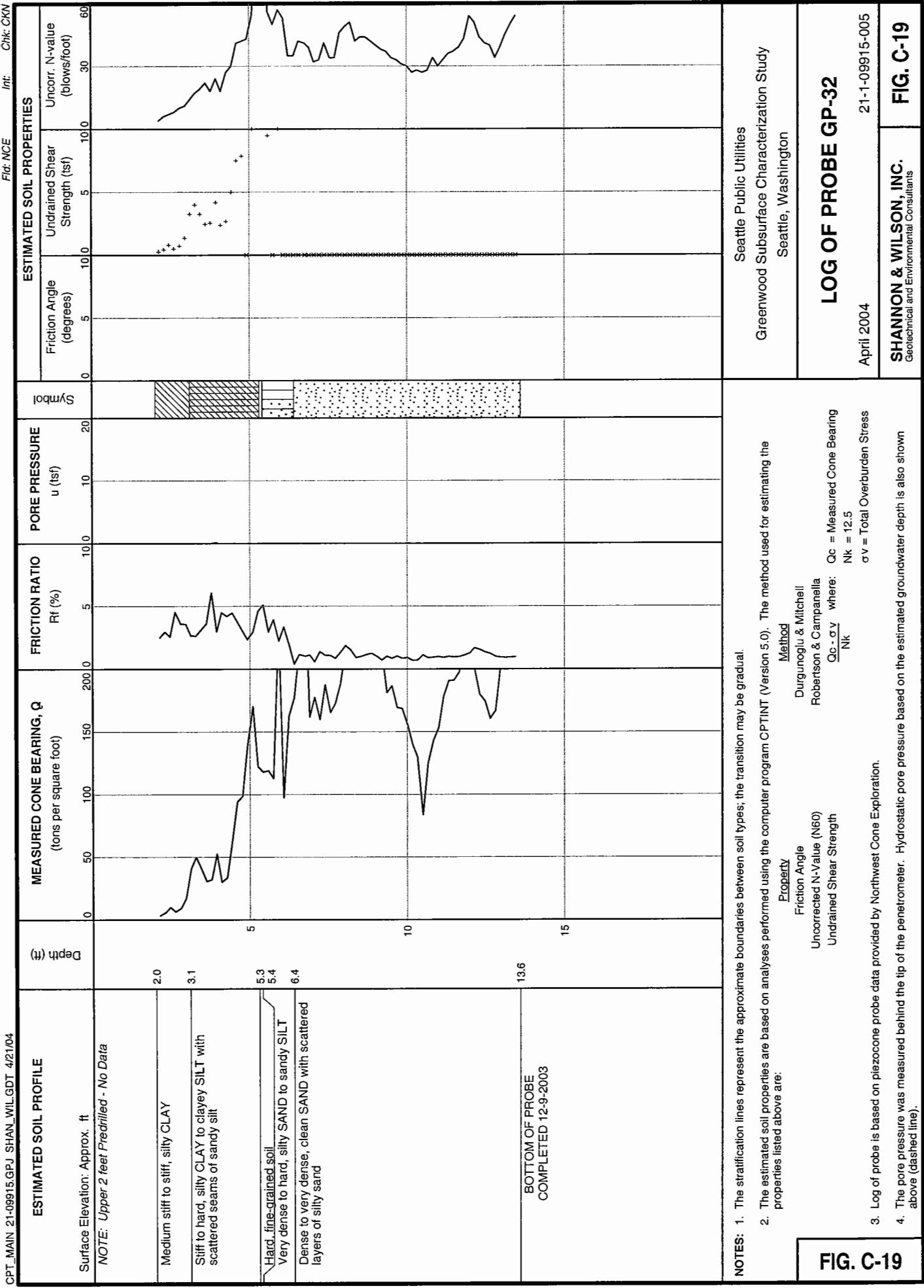


FIG. C-19

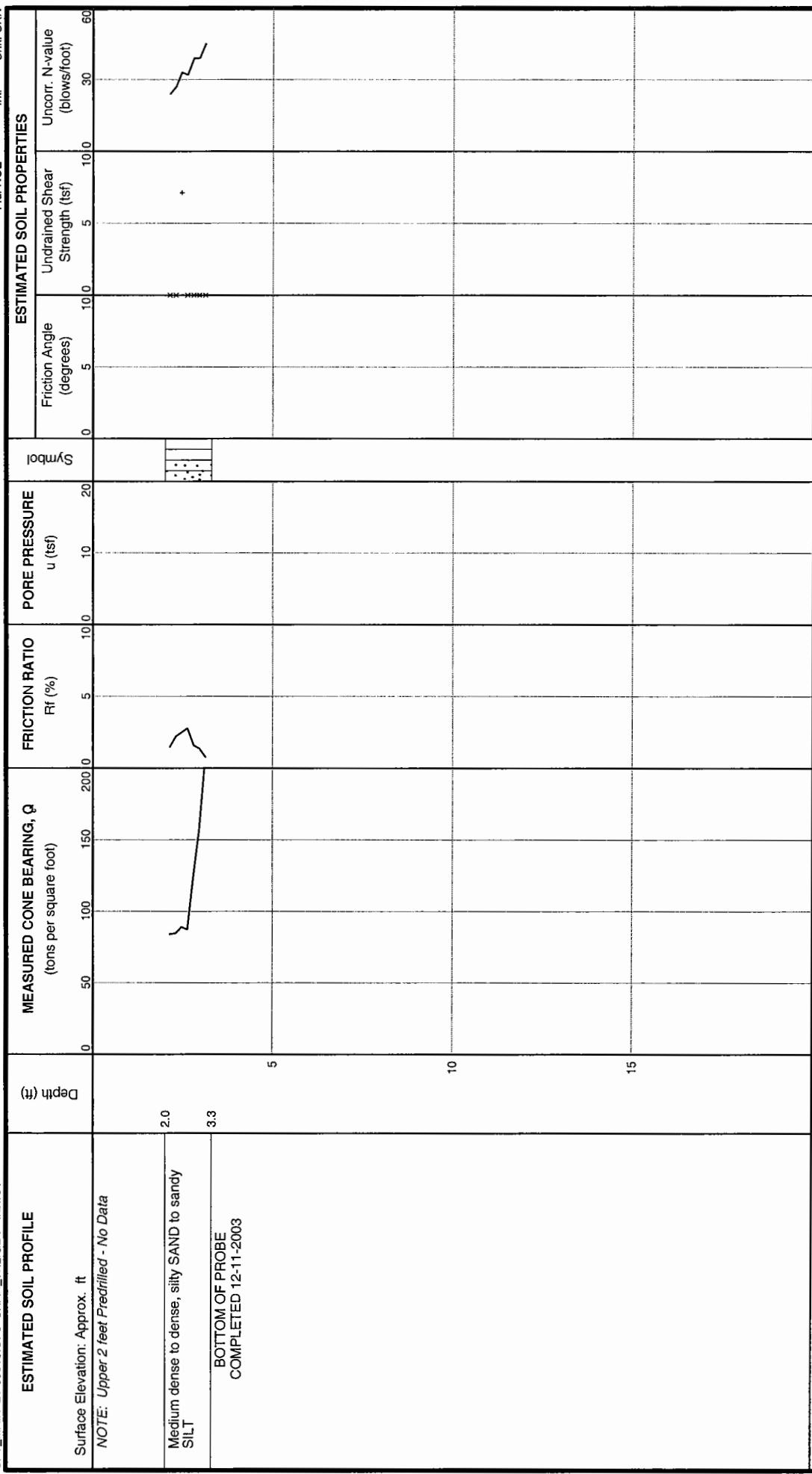
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FIG. C-19



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Friction Angle
Uncorrected N-Value (N60)
Undrained Shear Strength

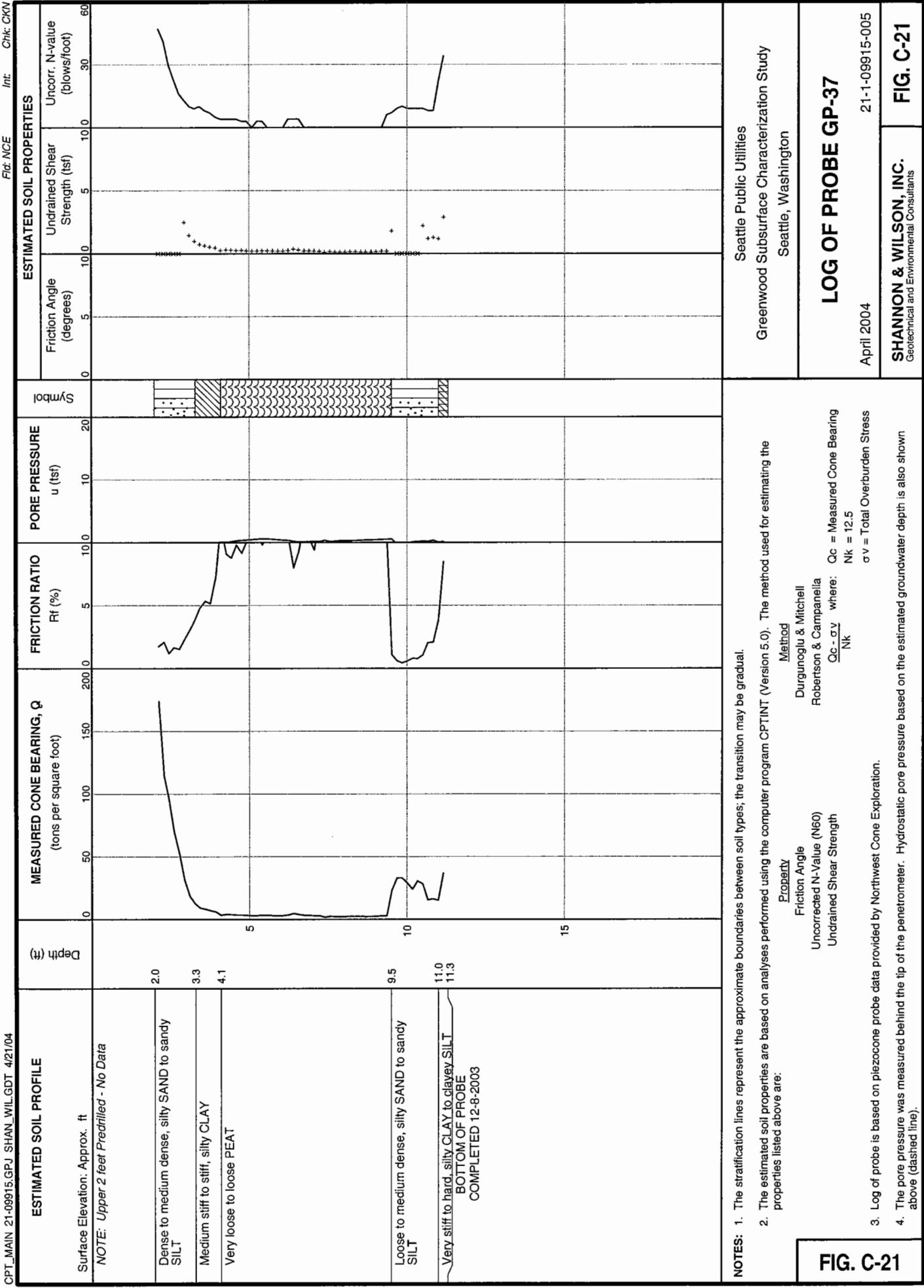
$$Nk = 12.5$$

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FIG. C-20

FIG. C-20

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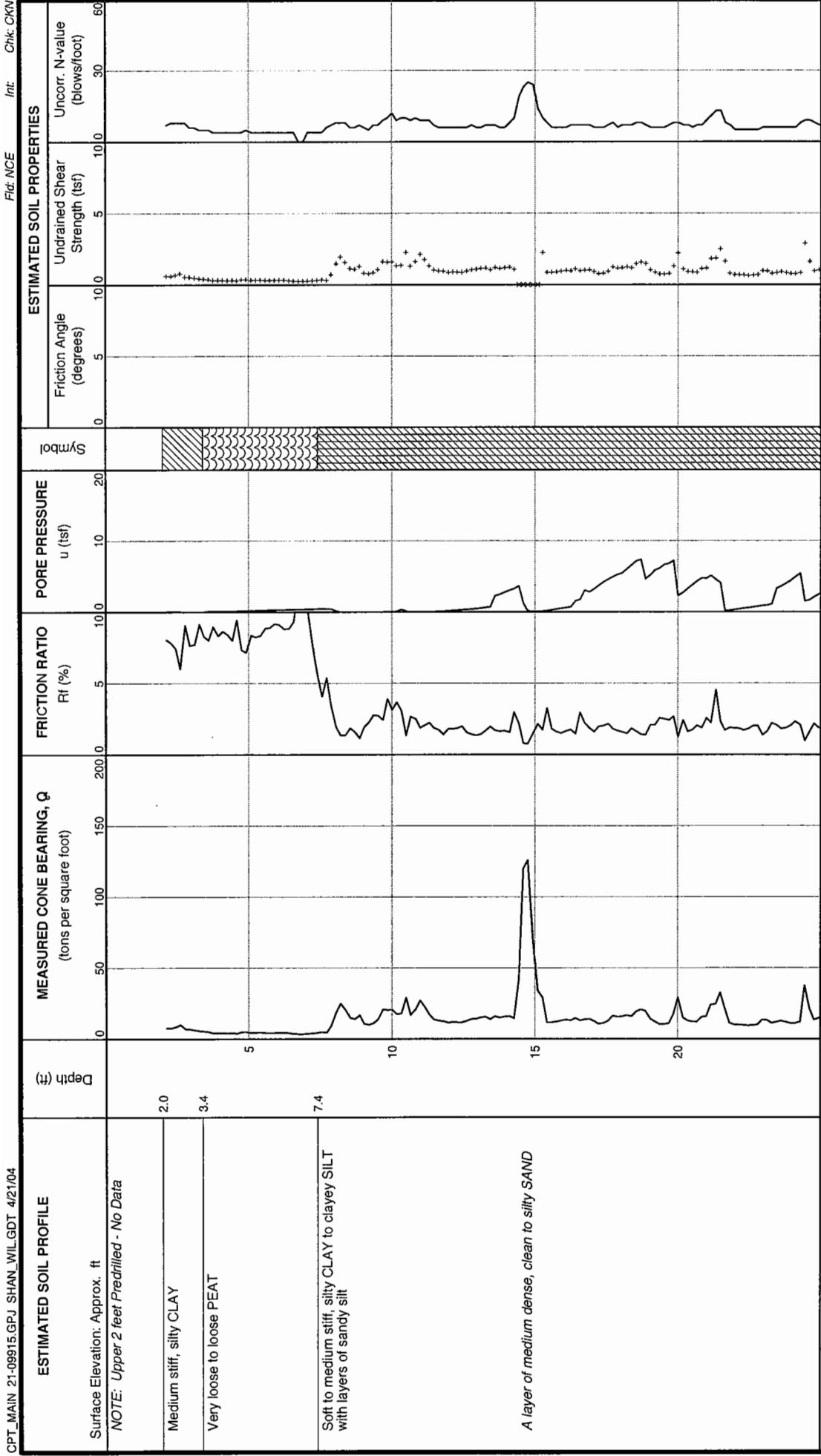
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LOG OF PROBE GP-37

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FIG. C-21



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (Version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Uncorrected N-Value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Q_c - \sigma_v}{N_k}$ Where: Q_c = Measured Cone Bearing
 N_k = 12.5
 σ_v = Total Overburden Stress

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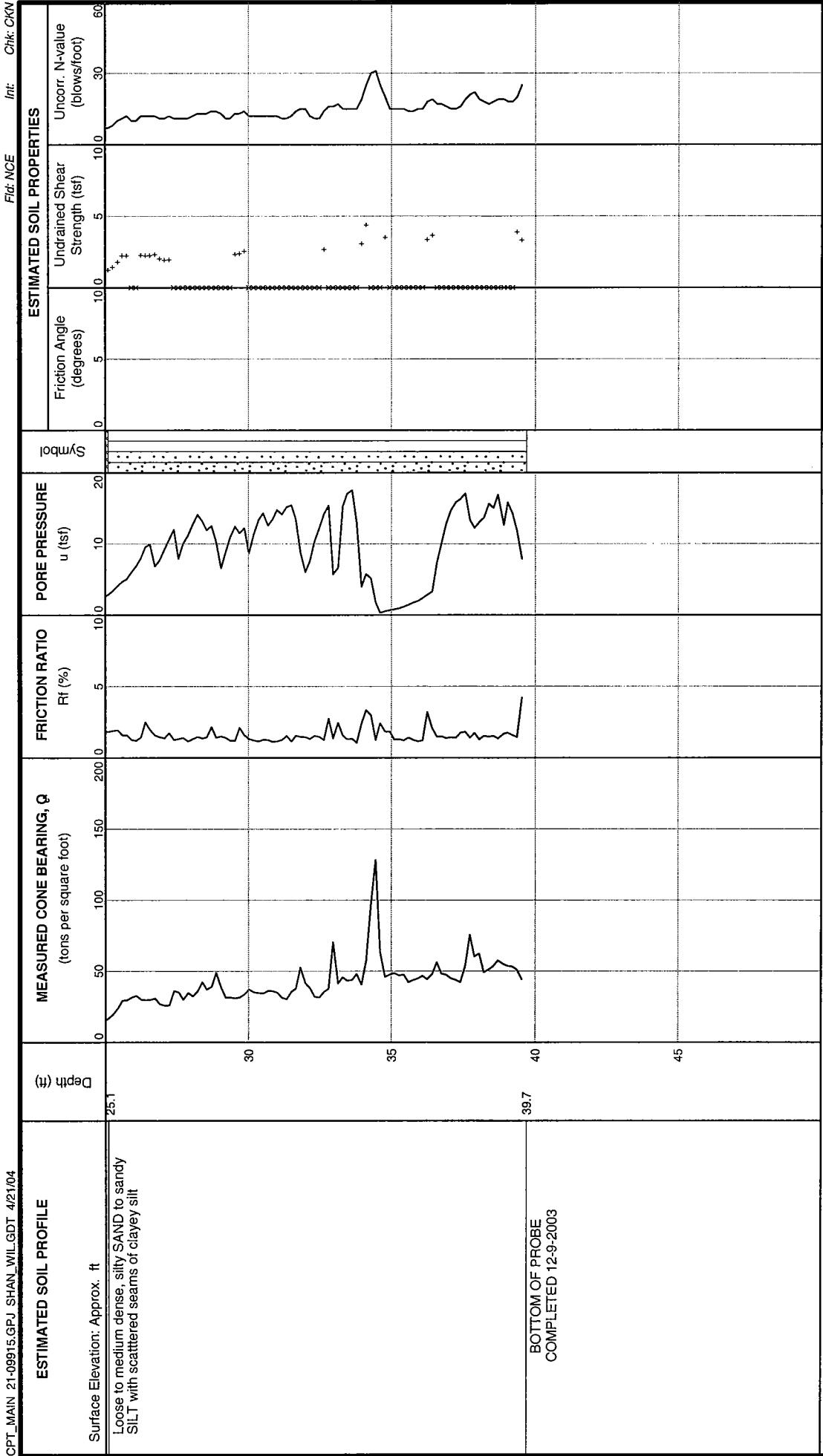
Greenwood Subsurface Characterization Study

Seattle, Washington

LOG OF PROBE GP-38

- Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.
- The pore pressure was measured behind the tip of the penetrometer. Hydrostatic pore pressure based on the estimated groundwater depth is also shown above (dashed line).
- Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.
- Log of probe is based on piezocene probe data provided by Northwest Cone Exploration.

FIG. C-22
Sheet 1 of 2



NOTES: 1. The stratification lines represent the approximate boundaries between soil types; the transition may be gradual.

2. The estimated soil properties are based on analyses performed using the computer program CPTINT (version 5.0). The method used for estimating the properties listed above are:

Property
Friction Angle
Unorrected N-Value (N60)
Undrained Shear Strength

Method
Durgunoglu & Mitchell
Robertson & Campanella
 $\frac{Q_c \cdot \sigma_v}{N_k}$ where:
 Q_c = Measured Cone Bearing
 N_k = 12.5

σ_v = Total Overburden Stress

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FIG. C-22
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FIG. C-22
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